Heatwaves and predictability - the role of Rossby waves and atmospheric waveguides

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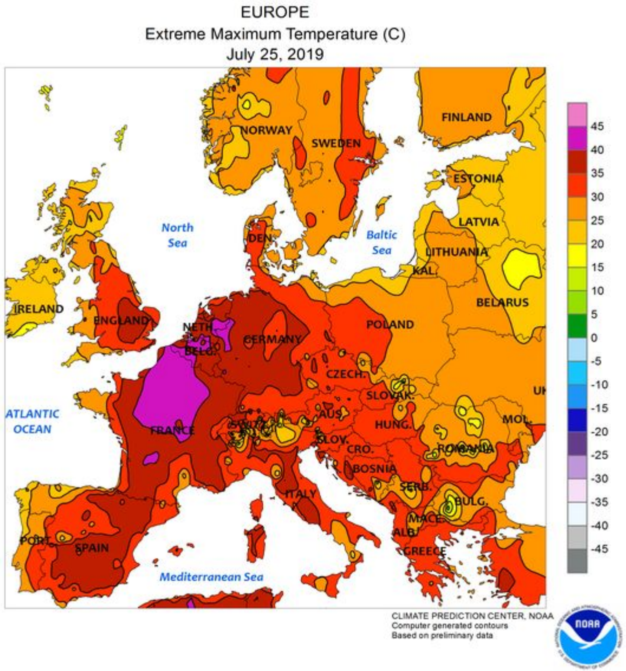
How are Rossby waves and associated waveguides connected with heatwaves in observation and seasonal forecast models?

Can Rossby wave dynamics help us understand and improve the seasonal and sub-seasonal predictability of heatwaves?

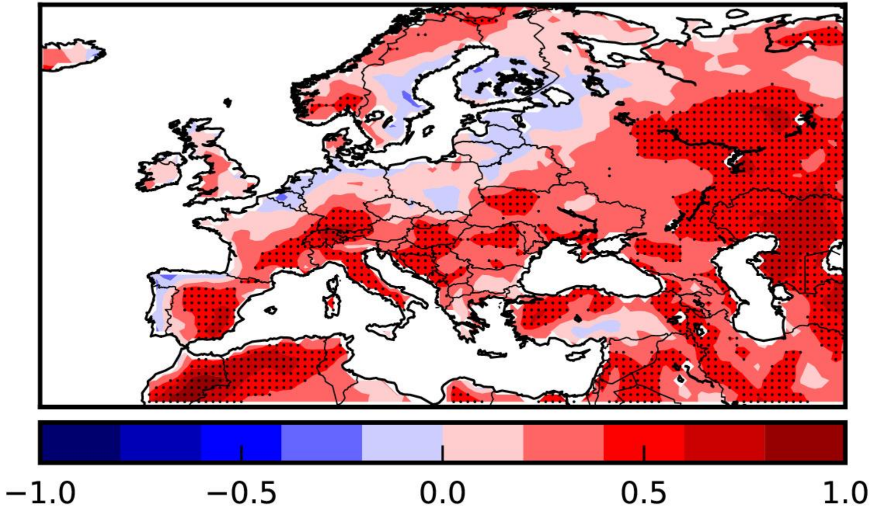


Introduction and Overview

- Previous work has shown that many **heatwaves** are associated with anomalous **atmospheric Rossby wave trains**. We explore this connection for in two seasonal forecast models (ECMWF System5, and Meteofrance System6) in the context of **quantifying and understanding the seasonal and subseasonal predictability of heatwaves**. In this work we focus on European summer heatwaves.
- This presentation shows the following key points:
  - There is **skill in seasonal predictions of "heatwave summers",** i.e. whether a particular summer will have a high or low heatwave index, based on the Heatwave Magnitude Index (HWMI) (slides 2 and 3).
  - Seasonal forecast models reproduce the **observed connection** between upper level **Rossby waves and surface extreme temperature** (slide 5), and they reproduce the **climatology of upper tropospheric Rossby waves** (slide 6);
  - There is a statistically significant connection between a seasonal average index of the HWMI averaged over Europe and an anomalous pattern of atmospheric waveguides (slide 7)
  - The models show a **positive correlation between observed and predicted northern hemisphere waveguide coverage** for one-month averages, particularly in mid-July to late-August (slide 8)
- Future work will continue to put these pieces together to better understand, and potentially improve, the predictability of heatwaves.

Seasonal predictions of heatwaves

Skill in predicting heatwaves

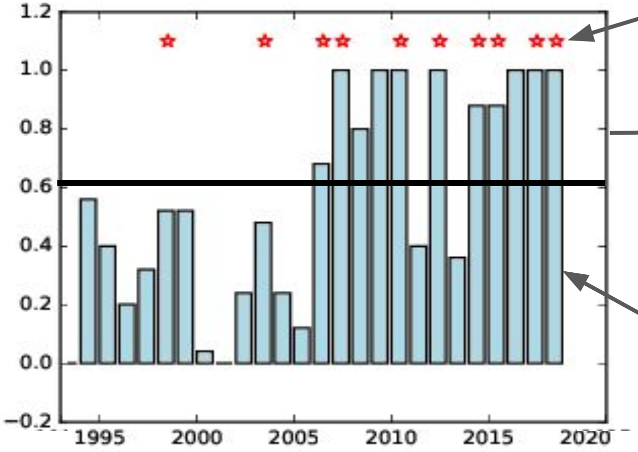


Correlation for seasonal prediction of heatwave for the ECMWF S5 system with ERA interim reanalysis (computed based on the Heatwave Magnitude Index (HWMI), Russo et al. 2014). Dots shows correlation significant at the 95% level. See appendix for more details on the HWMI

- Skill to predict heatwave amplitude for the whole summer season is significant, and therefore potentially useful, in a large part of Europe.

Seasonal predictions of heatwaves

Probability of extreme heatwaves



Red star = occurrence of a large heatwave in observations

Fraction of members forecasting a large heatwave

We consider a heatwave to be successfully forecasted if at least 80% of the members predict the occurrence of a large heatwave.
The corresponding probabilistic scores are the following:

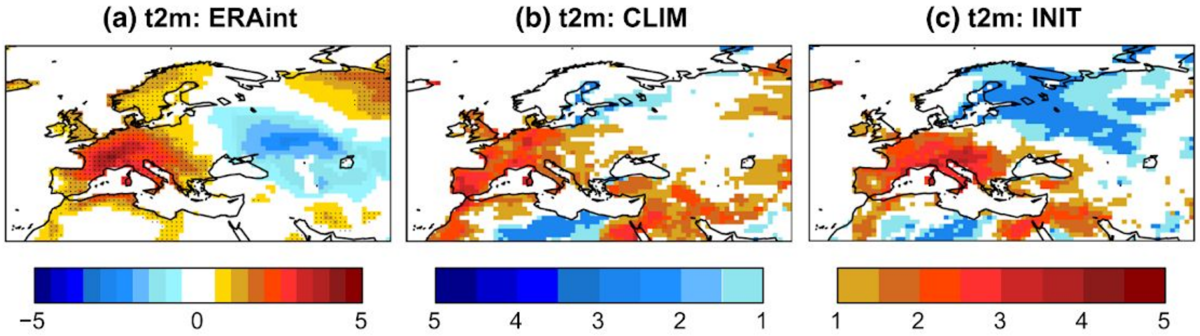
Hit: 7
Miss: 3
False Alarm: 2
Correct Rejection: 14
Accuracy: 0.81
Hit Rate: 0.700
TS: 0.583
ETS: 0.414

Detection of large heatwave (amplitude and spatial extension belonging to highest quintile) for the May to July period for the whole Europe (15ºW-50ºW-30ºN60ºN). Stars shows occurrence of a large heatwave in the observations and histogram the probability of occurrence among the member of ECMWF S5.

What are the sources of heatwave predictability?

- Heatwave predictability is strongly related to the warming trend.
- The soil moisture initial condition is also an important source of predictability (Prodhomme et al. 2016)
- However, even without without soil moisture initialization, seasonal forecasts seem to have some skill to predict some heatwaves, such as 2003 (see figure below). This suggests a possible role for atmospheric dynamics.

Seasonal prediction of the 2003 heatwave with EC-Earth 2.3 with soil moisture initialized with climatology (CLIM) or with realistic values (INIT)



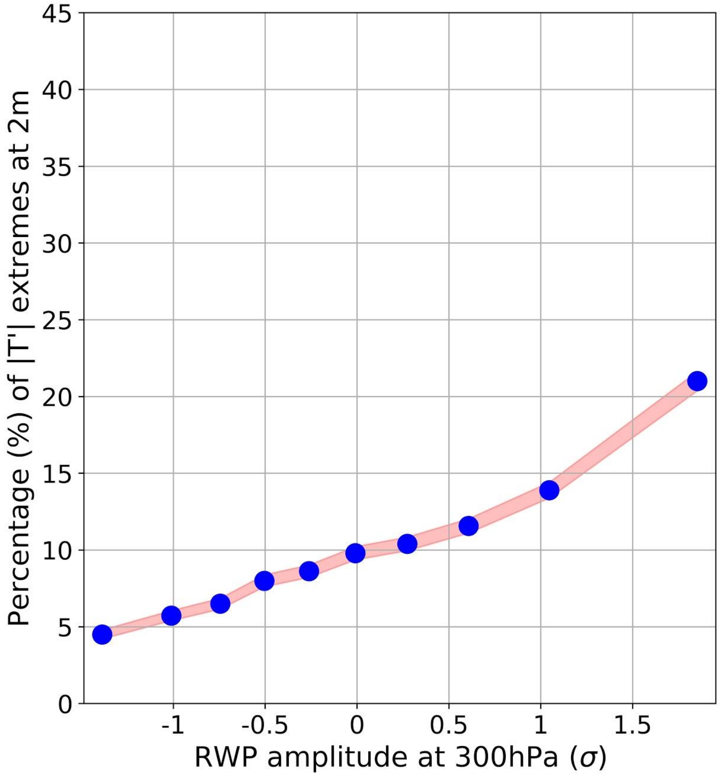
See appendix for more details on the odds ratio, which gives the forecast probability of temperatures in a given quintile relative to expected. In the figure (plots b and c) each gridpoint is attributed to the category corresponding to the highest odds ratio. If the point is attributed to the lower/upper quintile category, the corresponding odds ratio is plotted with the blue/red color scale. Thus red points are where the model predicts a high probability of t2m in the upper quintile; blue points are where the model predicts a high probability of t2m in the lower quintile.

a *Observed anomalies of t2m for 2003 JJA (K). Dots indicate where the anomaly is in the upper quintile (estimated over 1981–2010).* ***b*** *t2m odds ratio for seasonal forecasts initialised on May-01 with climatological soil moisture conditions (CLIM).* ***c*** *Same as* ***b****, but for forecasts initialized with observed soil moisture anomalies.*

Prodhomme et al. (2016)

Rossby wave packets and temperature extremes

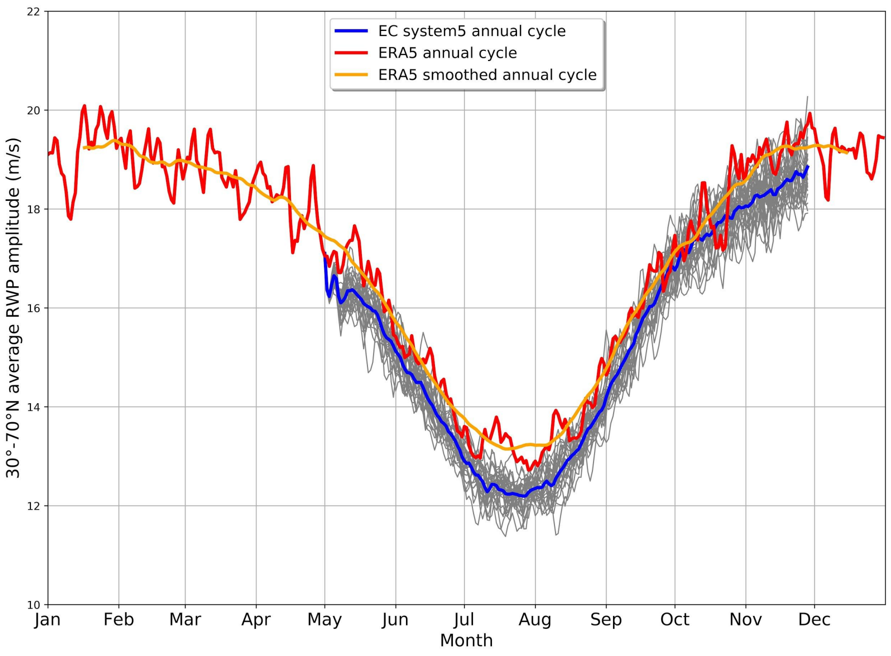
Temperature extremes versus RWP amplitude



- In both reanalysis and the ECMWF S2S system 5 (shown here for 1. May initializations) an increase in Rossby wave packet (RWP) amplitude over Europe is associated with an increase in the occurrence of temperature extremes (cold/hot) at 2m.

Representation of RWPs in ECMWF system 5

RWP amplitude seasonal cycle



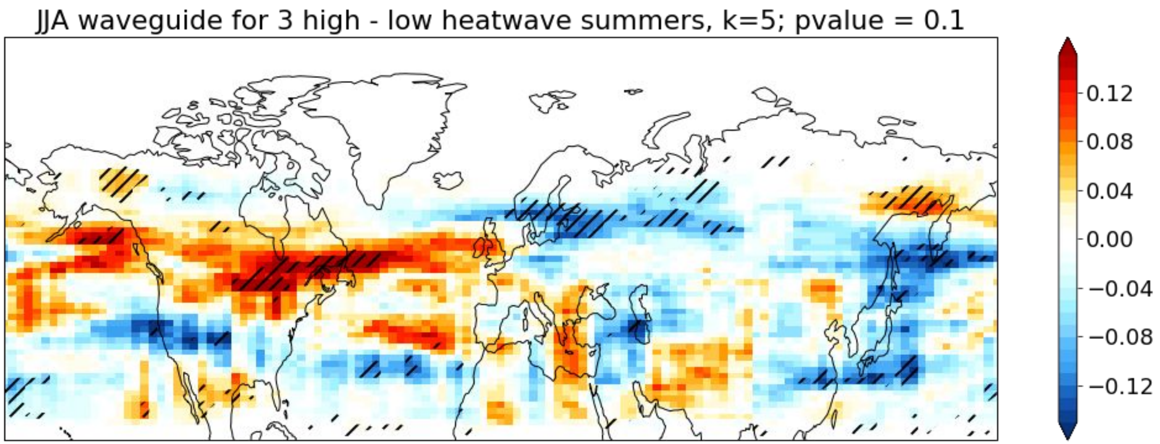
- The seasonal forecasts reproduce the observed seasonal cycle and approximate magnitude of Rossby wave amplitude
- Seasonal forecasts suffer from rapid decrease in NH-mean 300hPa waviness during the first few days after initialization
- A bias of approximately 5% builds up and is maintained throughout summer.
- June, July, and August initializations show similar behaviour.
- This relation suggests that the observed systematic underestimation in RWP amplitude may be a limiting factor in the predictability of strong summer heat waves.

Atmospheric waveguides and heatwaves

- Atmospheric waveguides, which affect the propagation of Rossby waves, are thought to be related to extremes (e.g. Hoskins and Woollings 2015).

- The figure shows the difference between composites of summer waveguide frequency for the years with the highest vs the lowest MJJA HWMI index averaged over Europe

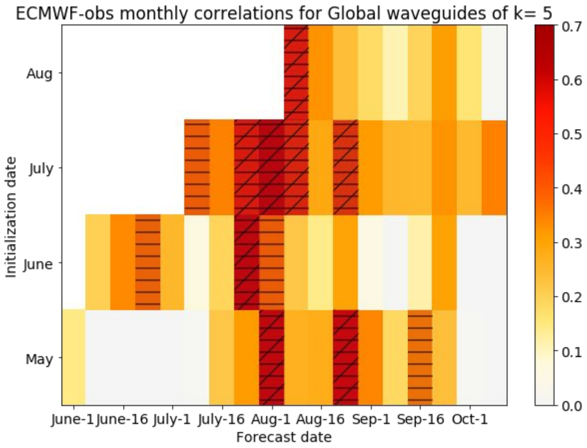
- Years with the highest HWMI show an increase in waveguide frequency upstream from Europe.



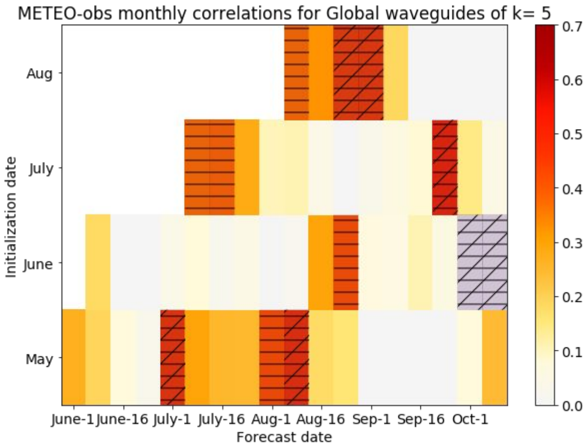
Anomalous JJA waveguide frequency for a composite of the 3 years (between 1993-2015) with the highest MJJA European HWMI (2010, 2003, 2006) relative to the 3 years with the lowest HWMI (1996,1994,1993). Black hatching shows significant differences at p<0.1 based on bootstrap resampling. The HWMI data are not de-trended - to do this we would need a method to separate the thermodynamic and dynamic trends; using de-trended data shows a weaker, but similar, pattern.

Seasonal prediction of Atmospheric waveguides

ECMWF system5



Meteofrance system6



Pearson correlation coefficient between forecasted and re-analysis NH waveguide anomalies for different forecast dates (x axis) and initialization months (y axis). Running 30 day means plotted every 7 days. Horizontal hatched values are significant at p<0.1, diagonal hatched at p<0.05.

- We calculate waveguides using the method of White (2019), with all zonal wind data re-gridded to a regular 3 degree grid prior to waveguide detection.
- The figure shows that there is seasonal predictability in average NH waveguide coverage; the ECMWF system5 model performs better than the Meteofrance system6.
- There seems to be a re-emergence of predictability in mid to late July.

Conclusions

- Extreme surface temperatures are associated with atmospheric Rossby waves in both re-analysis data and seasonal forecast models
- Seasonal forecast models show skill in the seasonal prediction of heatwave summers, soil moisture plays a role, but is not the only predictor.
- Composites of summers with the largest heatwave index (in amplitude and/or time) averaged over the European region show an increase in waveguide frequency upstream relative to summers with the lowest/smallest heatwave index.
- Significant sub-seasonal skill in predicting waveguide occurrence is obtained in two seasonal forecast systems with a maximum skill in July-August for initialization on 1st May, June and July.
- The implications of the subseasonal skill in waveguide occurrence for subseasonal skill in heatwave forecasting is the subject of on-going work.

References

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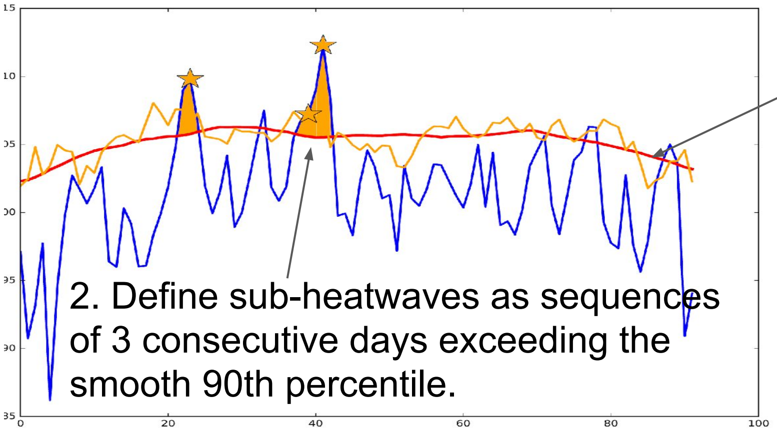
White, R.H., (2019), Detecting Waveguides for Atmospheric Planetary waves: Connections to Extreme Weather Events. Proceedings of the 9th International Workshop on Climate Informatics: CI 2019, Brajard, J., Charantonis, A., Chen, C., & Runge, J. (Eds.) https://doi.org/10.5065/y82j-f154

Appendix

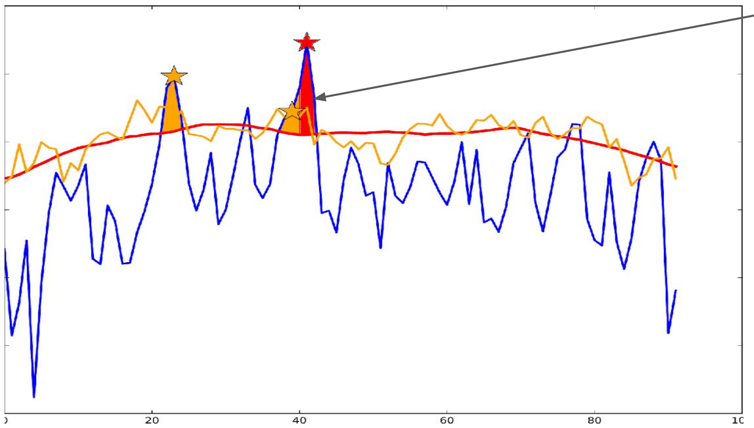
HWMI *(Russo et al. 2014)*

1. Compute the 90th percentile daily temperature climatology and smooth it using a 30-day running mean



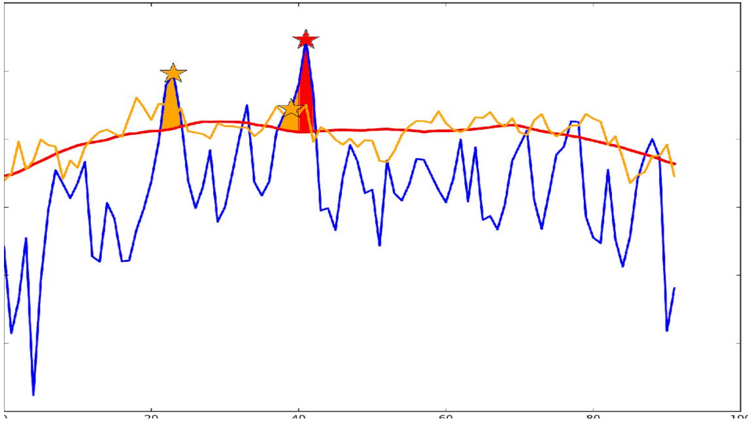
2. Define sub-heatwaves as sequences of 3 consecutive days exceeding the smooth 90th percentile.

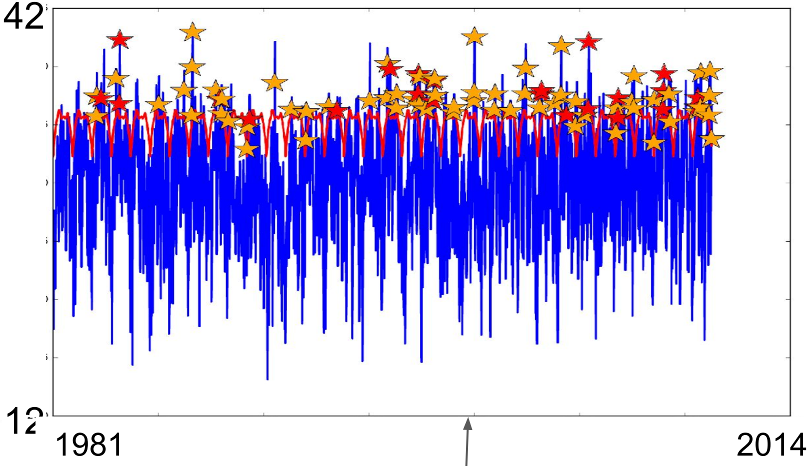
3. Sum the temperature over all days of each sub-heatwave and select the maximum sub-heatwave temperature sum for each season.



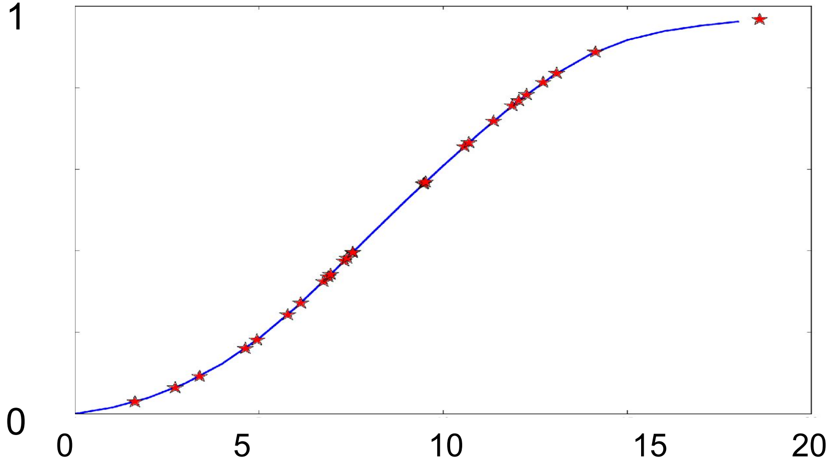
A heatwave lasting longer than 3 days would be split into several consecutive sub-heatwaves.

HWMI *(Russo et al. 2014)*



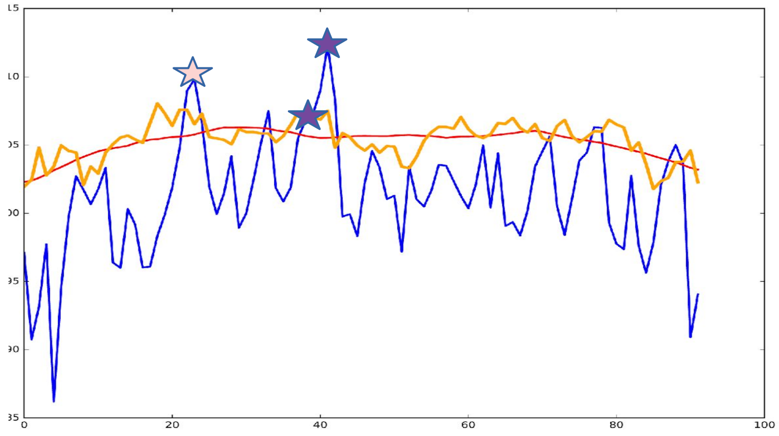


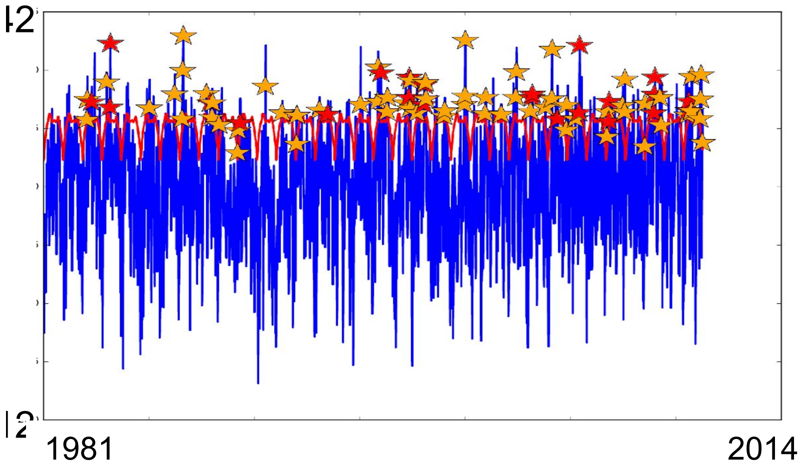
4. Repeat the first 3 steps for all years

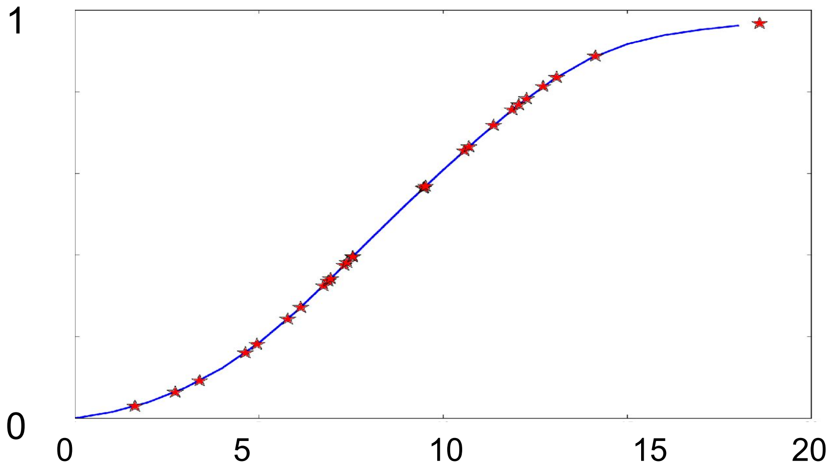


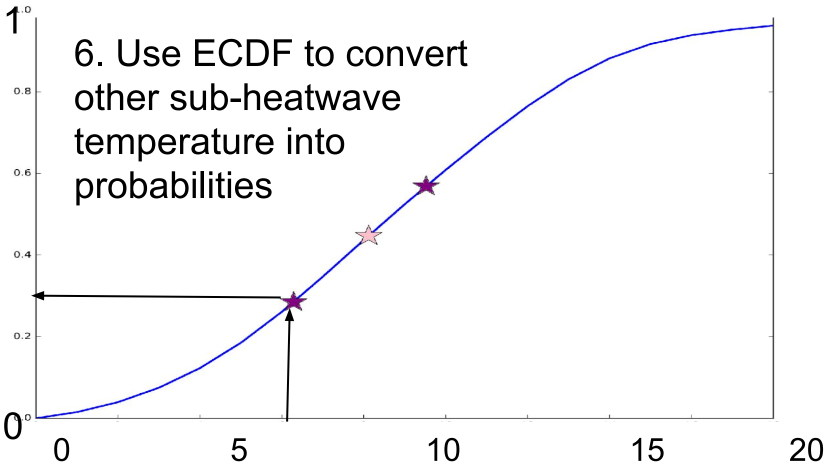
5. Use each year maximum sub-heatwave temperature sum to construct the empirical cumulative distribution function (ECDF)

HWMI *(Russo et al. 2014)*

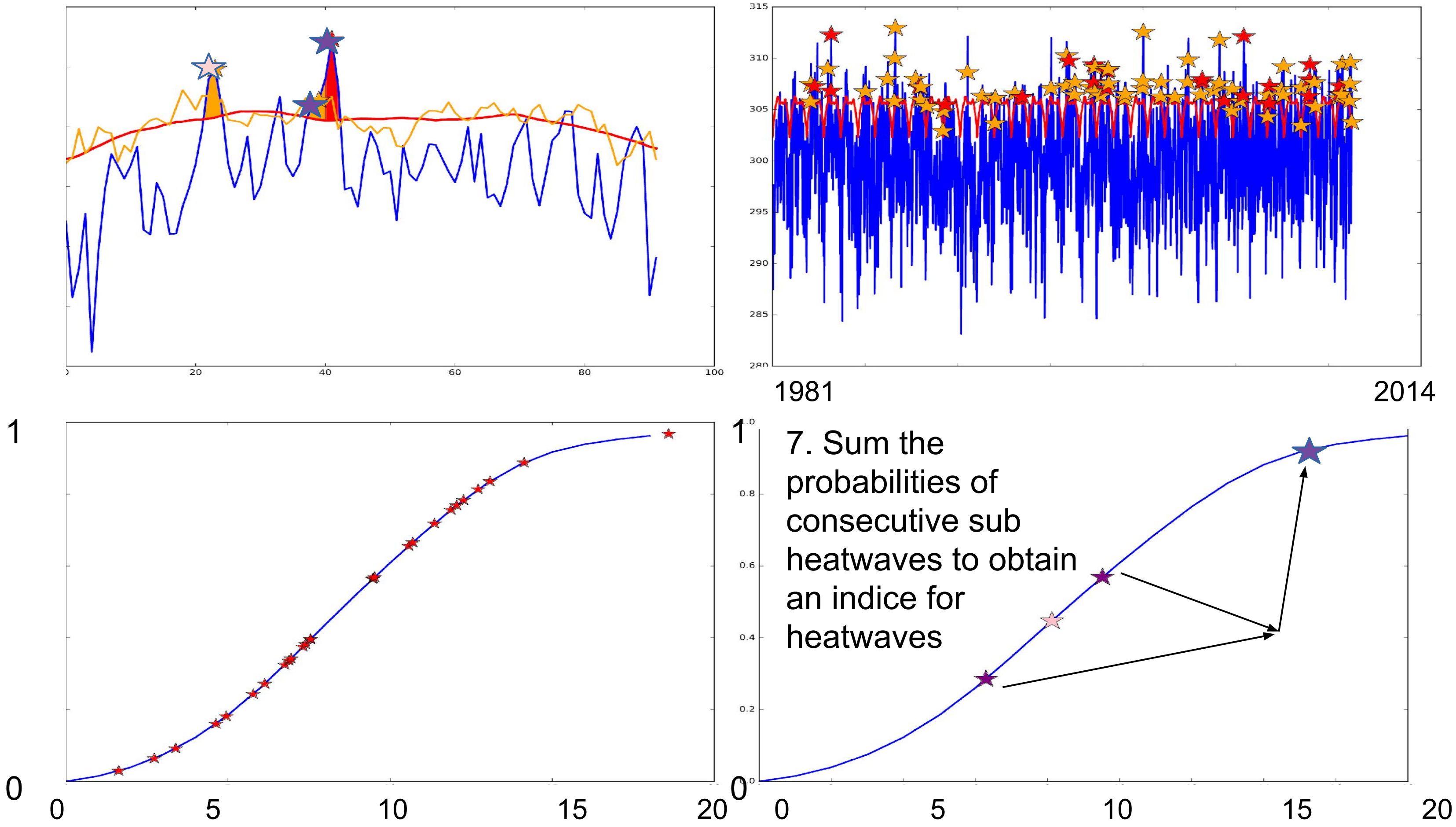




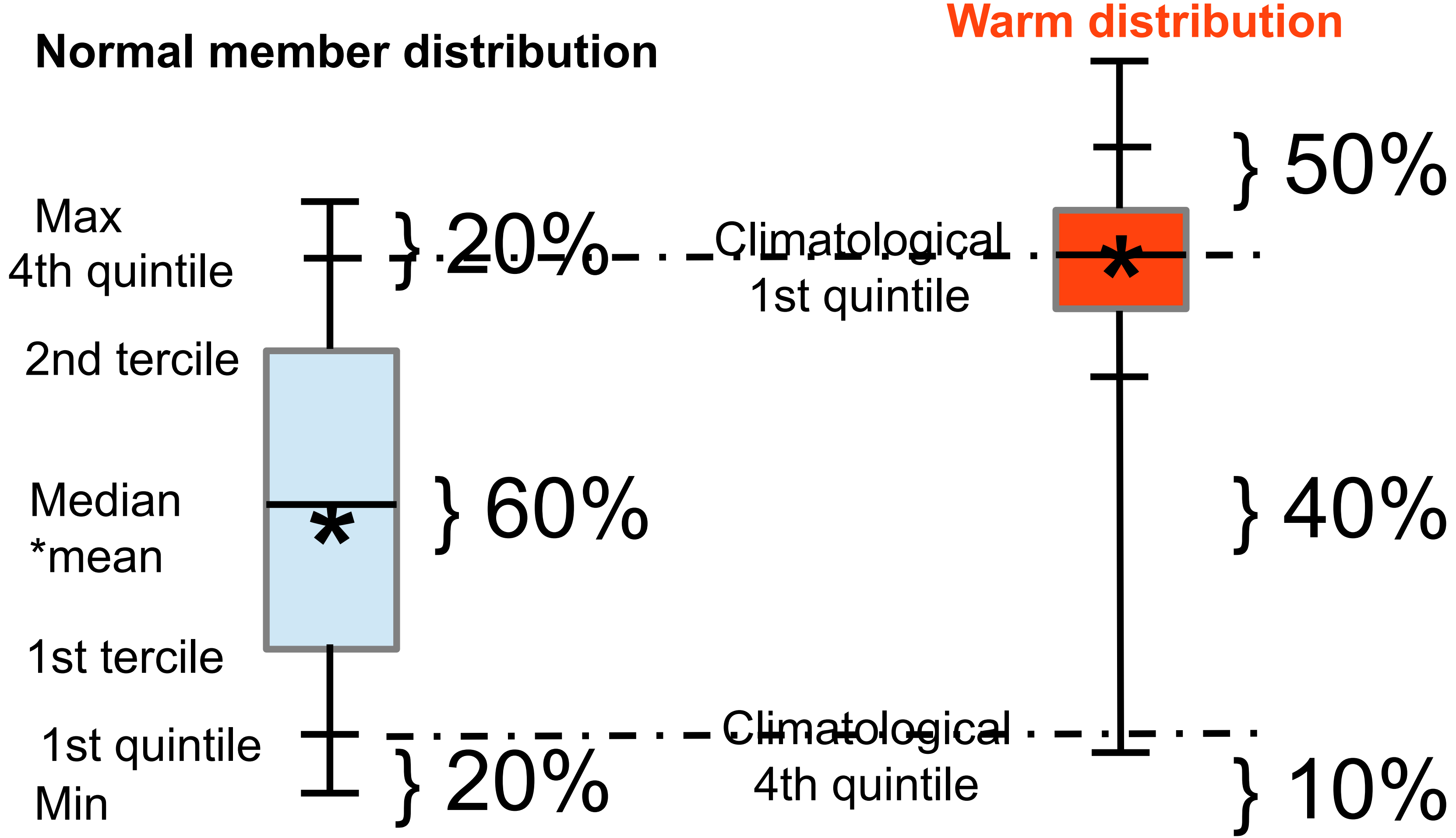




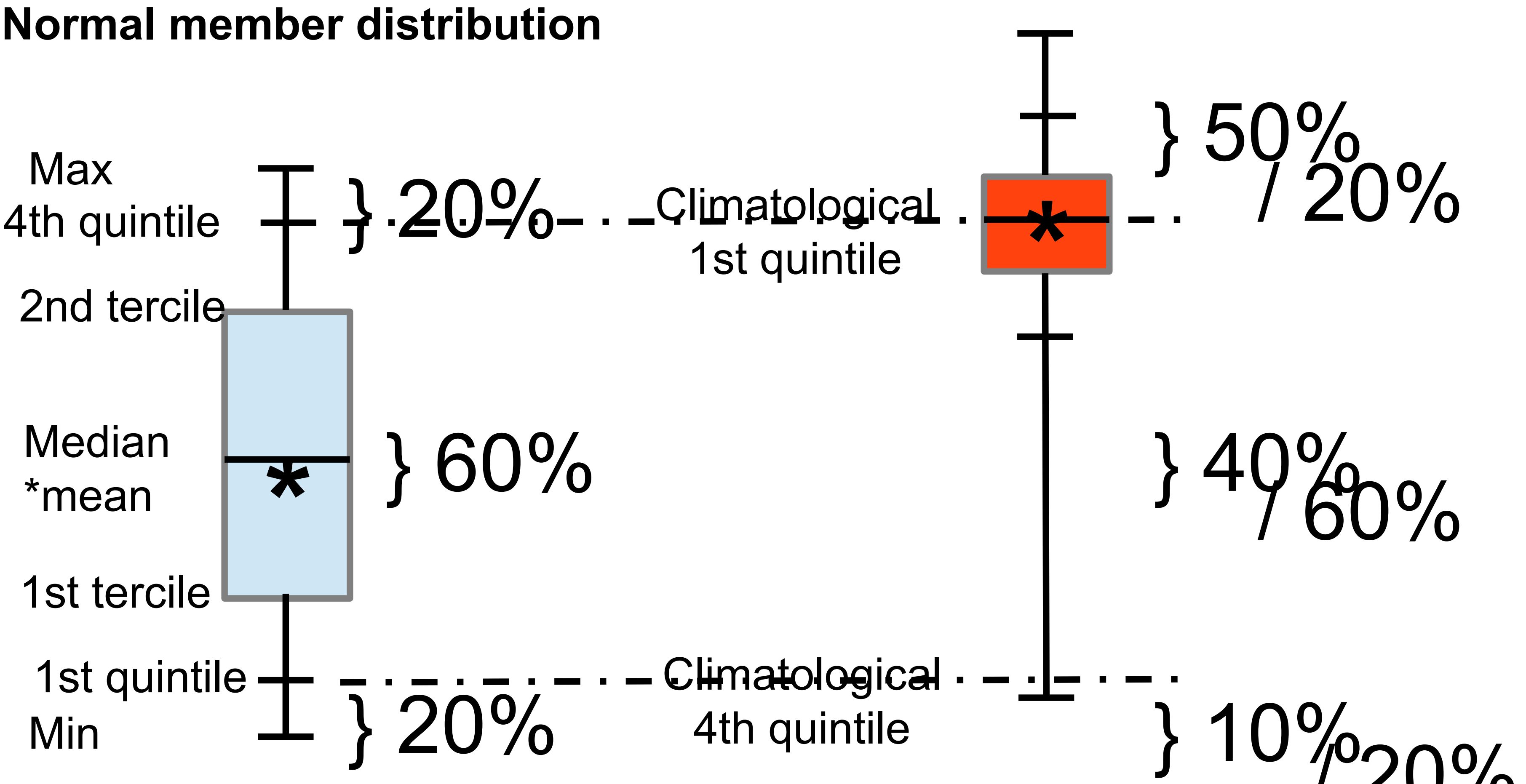
HWMI *(Russo et al. 2014)*



Odds ratio


Normal member distribution
Warm distribution
Max
4th quintile
2nd tercile
Median
*mean
1st tercile
1st quintile
Min
} 20%
} 60%
} 20%
Climatological
1st quintile
Climatological
4th quintile
} 50%
} 40%
} 10%

Odds ratio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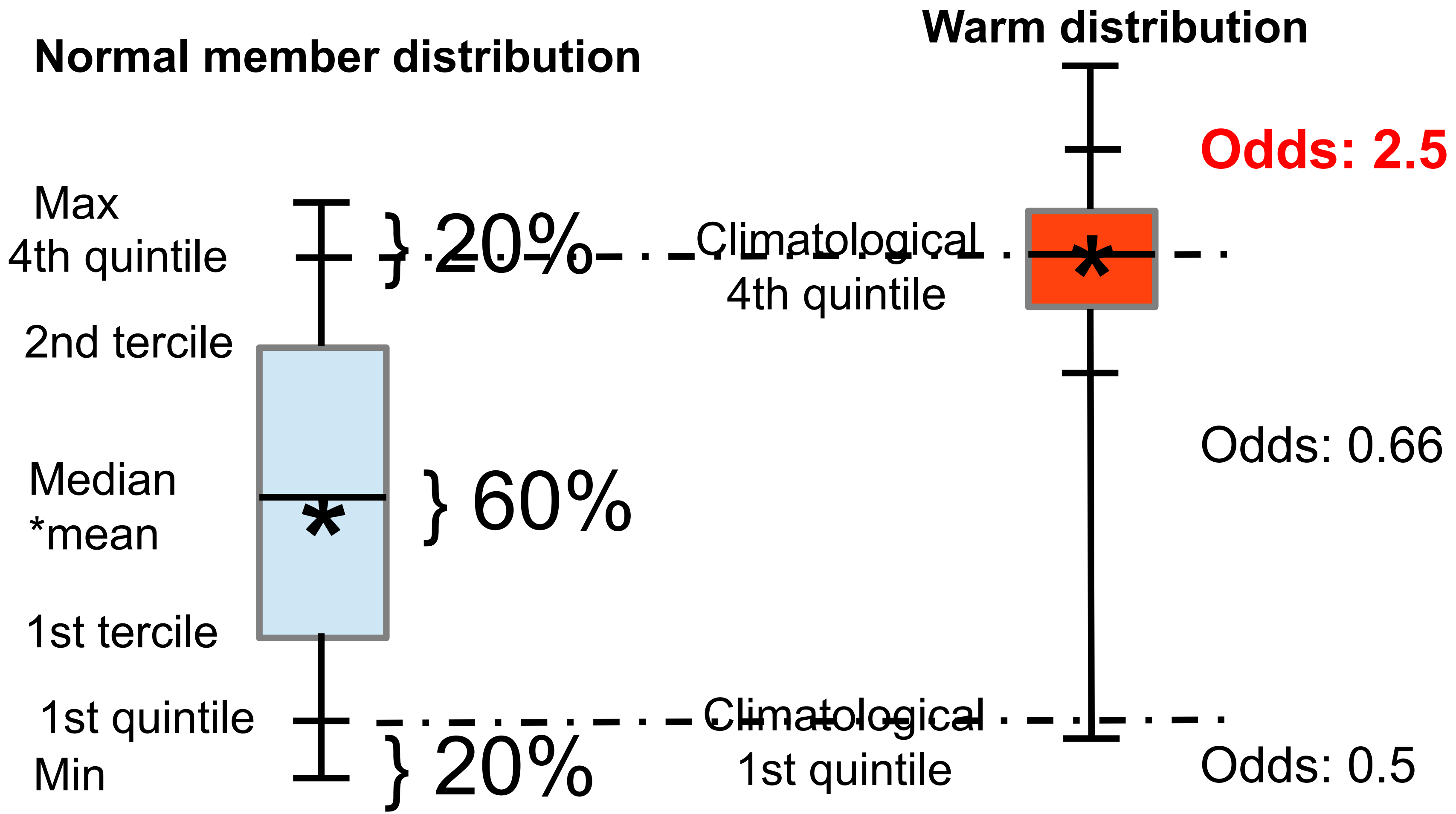
} 20%
} 60%
} 20%
Climatological
1st quintile
Climatological
4th quintile
} 50%
/ 20%
} 40%
/ 60%
} 10%
/20%

Odds ratio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Max
4th quintile
2nd tercile
Median
*mean
1st tercile
1st quintile
Min
} 20%
} 60%
} 20%
Climatological
4th quintile
Climatological
1st quintile
Odds: 2.5
Odds: 0.66
Odds: 0.5